CARRIER RECOVERY APPARATUS AND METHODS FOR HIGH-DEFINITION TELEVISION RECEIVERS

BACKGROUND OF THE INVENTION

This application claims priority from Korean Patent Application No. 10-2002-0061041, filed 7 October 2002 in the Korean Intellectual Property Office (KIPO), which is incorporated herein in its entirety by reference.

FIELD OF THE INVENTION

The present invention relates to receivers for use with a high-definition television (hereinafter, referred to as "HD TV") signal, and more particularly, to carrier recovery apparatus and methods that recover a carrier wave signal in, for example, a HD TV signal.

BACKGROUND

High-definition television receivers which are compatible with the advanced television systems committee (ATSC) standard receive a transmission signal that includes a pilot signal. Example transmission signals that include a pilot signal in a carrier wave include vestigial sideband (VSB) signals, double sideband (DSB) signals, and single sideband (SSB) signals. The pilot signal may be used to recover the carrier wave in a received signal.

FIG. 1 illustrates a data frame structure of a VSB signal. A data frame consists of two fields, and each field consists of 313 segments. A segment, which is a basic unit of a data frame, includes 832 symbols, and a segment synchronization signal having four symbols is provided at a beginning part of each segment.

A first segment of a field is a field synchronization signal that has a pattern that is known in advance by a transmitter and a receiver. The field synchronization signal is generated at predetermined instances of time. The other 312 segments, except for the first segment, contain data.

FIG. 2 illustrates the structure of the field synchronization signal shown in FIG. 1. Referring to FIG. 2, the field synchronization signal of FIG. 1

includes a PN511 signal, three PN63 signals, and a VSB mode signal. A field synchronization signal is included in every field and, thus, a PN511 signal, three PN63 signals, and a VSB mode signal are also included in each field.

FIG. 3 is a block diagram of a high-definition television receiving system 300. Operations for receiving a carrier wave in the receiving system 300 will now be described with reference to FIG. 3. First, a carrier wave signal input, received by an antenna, is applied to a tuner 310. The tuner 310 converts the received carrier wave signal into a signal of a certain bandwidth in response to a fixed local oscillating signal.

The signal output by the tuner 310 is filtered by a surface acoustic wave (SAW) filter 320 to provide a signal having certain bandwidth. Because the SAW filter 320 allows only signals of certain bandwidths to pass through, distortions in the carrier wave signal may result in the pilot signal being blocked by the SAW filter 320. Consequently, a carrier recovery device 350 may not be able to detect the pilot signal, and which may prevent recovery of the carrier wave.

The signal output by the SAW filter 320 is amplified through an intermediate frequency (IF) amplifier 330, converted into a digital signal *INS* by an analog-to-digital converter (ADC) 340, and a sampled signal is detected by a symbol timing recovering unit 360.

The digital signal INS from the ADC 340 is recovered by the carrier recovery device 350. A carrier recovery loop 370 recovers a carrier wave using a pilot signal in a carrier wave signal. Deviation of a pilot signal from the pass-through bandwidth of the SAW filter 320, because of, for example, distortion in the carrier wave signal, can result in a frequency offset, i.e., an offset between a carrier frequency and a demodulating frequency. The carrier recovery device 350 and the carrier recovery loop 370 extract the frequency offset between the carrier wave signal and the demodulated frequency, and operate as loops for compensating for the frequency offset and for compensating for phase errors.

A pilot signal may, however, weaken or vanish due to noise from, for example, multi-path affects on a transmission signal. Consequently, a receiving system may not be able to recover a carrier wave. Additionally, significant time may be necessary to synchronize a carrier wave when a large

carrier wave frequency error occurs in an early stage in the recovery of the carrier wave using the pilot signal.

SUMMARY OF THE INVENTION

Some embodiments of the present invention provide a carrier recovery apparatus that may be used in a high-definition TV receiver. The carrier recovery apparatus includes an error compensating unit, an error detecting unit, and an oscillator. The error compensating unit combines a complex input signal with a frequency signal to generate a complex output signal. The complex output signal includes an error reference signal. The error detecting unit determines a location of the error reference signal in the complex output signal based on a real part of the complex output signal, and generates an error signal based on that location. The oscillator generates the frequency signal with a frequency that varies based on the error signal. The complex input signal may be a VSB signal that is represented as a complex number, and the error reference signal may be a PN63 signal in a field synchronization signal of the complex input signal.

The carrier recovery apparatus may be used to quickly recover a carrier even when a pilot signal is difficult to detect. For example, in some embodiments, a PN63 signal that is contained in a field synchronization signal of a VSB signal is used to recover the carrier.

Some other embodiments of the present invention provide a method of recovering a carrier in a complex high-definition TV signal. The presence or absence of a pilot signal in the complex high-definition TV signal is detected. A selection is then made between performing a first error detecting function on the complex high-definition TV signal and performing a second error detecting function on the complex high-definition TV signal based on the detected presence or absence of the pilot signal in the complex high-definition TV signal. In some further embodiments, the first error detecting function uses the PN63 signal that is contained in a field synchronization signal of the VSB signal to recover the carrier. The second error detecting function may recover the carrier using the pilot signal. Accordingly, the carrier may be recovered using the pilot signal when it is available, and may otherwise use the PN63 signal to recover the pilot signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a data frame structure of a vestigial sideband (VSB) signal according to the prior art;

FIG. 2 illustrates the structure of a field synchronization signal of the VSB signal of FIG. 1 according to the prior art;

FIG. 3 is a block diagram of a high-definition TV receiver according to the prior art;

FIG. 4 is a block diagram of a carrier recovery apparatus according to a first embodiment of the present invention;

FIG. 5 is a block diagram of a frequency error measuring unit, for example, as shown in FIG. 4, according to embodiments of the present invention;

FIG. 6 is a flowchart of operations for recovering a carrier according to the first embodiment of the present invention;

FIG. 7 is a flowchart of operations for determining location of an error reference signal and generating an error signal according to embodiments of the present invention;

FIG. 8 is a flowchart of operations for generating an error signal, for example, as shown in FIG. 7, according to embodiments of the present invention;

FIG. 9 is a block diagram of a carrier recovery apparatus according to a second embodiment of the present invention;

FIG. 10 is a flowchart of operations for recovering a carrier according to the second embodiment of the present invention; and

FIG. 11 is a flowchart of operations for generating an error signal, for example, as shown in FIG. 10.

DETAILED DESCRIPTION OF THE INVENTION

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which illustrative embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so

that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numerals refer to like elements throughout.

As will be appreciated by one of skill in the art, the present invention may be embodied as methods and apparatus. Accordingly, the present invention may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects, all of which are generally referred to herein as "device", "apparatus", and "unit". The present invention is described below with reference to flowchart illustrations and/or block diagrams of methods and apparatus or receivers according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

These computer program instructions may also be stored in a computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including instruction means which implement the function/act specified in the flowchart and/or block diagram block or blocks.

The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide steps for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

FIG. 4 is a block diagram of a carrier recovery device (apparatus) 400

according to a first embodiment of the present invention, and FIG. 5 is a block diagram of a frequency error measuring unit such as, for example, as shown in FIG. 4.

Referring to FIGs. 4 and 5, the carrier recovery device 400 includes an error compensating unit 410, a switching unit 415, a switch control signal generator 420, a first error detecting unit 425, and a second error detecting unit 440.

The error compensating unit 410 multiplies a complex input signal *COMIS* that includes a real number portion and an imaginary number portion by a predetermined frequency signal *FRQS* that is output from the second error detecting unit 440, and outputs the multiplication result as a complex output signal *COMOS*.

The complex input signal *COMIS* is an input signal *INS* that is converted into a complex number signal through a complex filter 405. The input signal *INS* is a carrier wave signal that may be received, for example, through an antenna, cable conduit, network, or other communication medium, and output as a real-number signal through, for example, the ADC 340 of FIG. 3. The carrier recovery device 400 may be used in a receiver of an 8-level vestigial sideband (VSB) HD TV signal, such as, for example, one that is configured for use in the United States. In such case, the complex input signal *COMIS* may be a VSB signal that is converted into a complex number.

The complex input signal *COMIS*, which may include an error, is combined by, for example, multiplying it with the frequency signal *FRQS* to generate a complex output signal *COMOS*. The complex output signal *COMOS* is based on the complex input signal *COMIS* but can include error compensation by the use of the frequency signal *FRQS*. The frequency signal *FRQS* can be generated by an oscillator 455 in the second error detecting unit 440 that is responsive to signals from the first error detecting unit 425 and/or the second error detecting unit 440. Operation of the first and second error detecting units 425 and 440 is further described below.

The error compensating unit 410 may multiply the complex input signal *COMIS* by the frequency signal *FRQS* to generate the complex output signal *COMOS*. When the complex input signal *COMIS* is first applied to the error compensating unit 410, the frequency signal *FRQS* may not contain

information that would allow the error compensating unit 410 to compensate for error in the complex input signal *COMIS*, and accordingly, the complex output signal *COMOS* may be the same as the complex input signal *COMIS*.

The switch control signal generator 420 generates a switch control signal *SWCONS* based on whether or not a pilot signal is detected (sensed) in, for example, the complex input signal *COMIS* and/or the complex output signal *COMOS*. Based on the switch control signal *SWCONS*, the complex output signal *COMOS* is input to the first error detecting unit 425 when the pilot signal is not detected, and to the second error detecting unit 440 when the pilot signal is detected.

The switching unit 415 selectively provides the complex output signal COMOS to the first or second error detecting unit 425 or 440 based on the switch control signal *SWCONS*. When the pilot signal detected in, for example, the complex output signal *COMOS*, the complex output signal *COMOS* is applied to the second error detecting unit 440. The second error detecting unit 440 receives the complex output signal *COMOS* and compensates for error in the complex output signal *COMOS* using the pilot signal.

The second error detecting unit 440 includes a frequency-phase synchronization loop 445 that detects frequency and phase errors of a pilot signal in the complex output signal *COMOS*; a loop filter 450 that filters an output of the frequency-phase synchronization loop 445; and an oscillator 455 that generates the frequency signal *FRQS* whose frequency changes in response to an output of the loop filter 450 and an error signal *OFFSETS*. The operations of the second error detecting unit 440 may be, for example, those of a conventional carrier recovery device, and consequently, further description of those operations will not be provided for brevity.

If the pilot signal is not detected in, for example, the complex output signal *COMOS*, the switching unit 415 provides the complex output signal *COMOS* to the first error detecting unit 425 in response to the switch control signal *SWCONS*.

The first error detecting unit 425 receives the complex output signal *COMOS* and a real-number signal *REALS*, which represents a real part of the complex output signal COMOS, and detects the location of an error reference

signal in the complex output signal *COMOS* from the real-number signal *REALS*. The first error detecting unit 425 measures a variation in a phase angle of the complex output signal *COMOS* and applies the error signal *OFFSETS* as the result of the measurement to the oscillator 455 of the second error detecting unit 440.

The error reference signal may be a PN63 signal that is present in a field synchronization signal contained in the complex input signal *COMIS*. The first error detecting unit 425 detects a frequency offset of the complex output signal *COMOS* using, for example, the PN63 signal field synchronization signal instead of using the pilot signal. The field synchronization signal may be, for example, repeatedly generated at intervals of 24.2 ms and three PN63 signals may be included in each field synchronization signal.

The sign of a second one the three PN63 signals may change when the field synchronization signal is generated. Consequently, the second PN63 signal of every second field synchronization signal, generated at intervals of 48.4 ms, has the same sign, and which may be used to estimate a frequency offset of the complex output signal *COMOS*.

The field synchronization signal is detected by the field synchronization detector 430 and the frequency offset of the complex output signal *COMOS* is estimated by the frequency error measuring unit 435.

The field synchronization detector 430 determines location of a beginning and an end of the error reference signal based on the real-number signal *REALS*. For example, the field synchronization detector 430 determines the location of the PN63 signal of the field synchronization signal in the complex output signal *COMOS*, and generates a signal *FSO* as the result to the frequency error measuring unit 435. Operations for detecting the field synchronization signal from the VSB signal and detecting the PN63 signal from the field synchronization signal may include, for example, those which are well known to those skilled in the art, and thus, further description thereof will be omitted for brevity.

The frequency error measuring unit 435 receives the complex output signal *COMOS*; measures a variation in a phase angle in response to the signal *FSO* output from the field synchronization detector 430, using a

variation in the position of the error reference signal repeatedly generated, for example, in each, frame; and outputs an error signal *OFFSETS* as the result of the measurement.

The error signal *OFFSETS* is calculated by the frequency error measuring unit 435 using, for example, Equation (1) below:

$$\Delta F = 1/(2 * \pi * L)\ \tan^{-1}[\sum_{n=0}^{L-1} \mathrm{Im}\{y(n+L)\, y(n)^*\} / \sum_{n=0}^{L-1} \mathrm{Re}\{y(n+L)\, y(n)^*\}], \ldots \quad (1)$$

where ΔF is the error signal *OFFSETS*, $y(n)$ is the complex output signal *COMOS*, $y(n+L)$ is the complex output signal *COMOS* with a period that is delayed an amount L, $y(n)^*$ is a conjugate signal representation of the complex output signal *COMOS*, and L is the length of a sample of the error reference signal. For example, the length of the PN63 signal sample can be 63, so that L is 63.

Using Equation (1), the phase may be measure for a signal that is provided to the frequency error measuring unit 435, i.e., the complex output signal *COMOS*. A variation in the frequency offset of the complex output signal *COMOS* is calculated by, for example, measuring the phase of the complex output signal *COMOS* in the form of a phase angle with respect to the real axis, and calculating a variation in the phase angle. The variation in the frequency offset is the frequency error of the complex output signal *COMOS*.

Equation (1) includes operations for multiplying the signal $y(n+1)$, which corresponds to the complex output signal *COMOS* whose period is delayed by an amount L, by the conjugate signal $y(n)^*$ of the complex output signal *COMOS*, and then, adding the multiplication results together. The term n is an integer from 0 to L-1. These operations may correspond to, for example, correlation operations which are well known to those skilled in the art.

Referring to FIG. 5, the frequency error measuring unit 435 is shown according to some embodiments of the present invention. The frequency error measuring unit 435 may perform operations corresponding to, for example equation (1), using a delayer 510, a conjugate signal generator 520, a first multiplier 530, an imaginary-number generator 540, a real-number

generator 550, a second multiplier 560, an operation means 570, and a third multiplier 580. The delayer 510 receives the complex output signal *COMOS* and delays its period by an amount *L*. The conjugate signal generator 520 receives the complex output signal *COMOS* and generates a conjugate complex output signal representing a conjugate of the complex output signal *COMOS*. The first multiplier 530 multiplies the output of the delayer 510 by the conjugate complex output signal. The imaginary-number generator 540 extracts the imaginary part of the output of the first multiplier. The real-number generator 550 extracts the real part of the output of the first multiplier 530 and generates the reciprocal of the extracted real part. The second multiplier 560 multiplies the output of the imaginary-number generator 540 by the output of the real-number generator 550. The operation means 570 calculates the arctangent of the output of the second multiplier 560. The third multiplier 580 multiplies the output of the operation means 570 by a predetermined coefficient signal *COFS* to generate the error signal *OFFSETS*. The coefficient signal *COFS* is calculated by $1/(2*\pi*L)$, where L is the length of the error reference signal sample.

The error signal *OFFSETS* generated by the frequency error measuring unit 435 is provided to the oscillator 455 of the second error detecting unit 440. The oscillator 455 may be, for example, a numerically controlled oscillator. The oscillator 455 generates a frequency signal *FRQS* based on the error signal *OFFSETS*. The error compensating unit 410 combines, such as by multiplying, the frequency signal *FRQS* by the complex input signal *COMIS* to generate the complex output signal *COMOS*, in which error is reduced or compensated. The complex output signal *COMOS* is repeatedly passed through the loops of the first error detecting unit 425, the oscillator 455, and the error compensating unit 410 until, for example, error in the complex output signal *COMOS* is sufficiently reduced or eliminated. The complex output signal *COMOS* may be output to the outside of the carrier recovery device 400.

When the switch control signal *SWCONS* is initially provided to the switching unit 415, the complex output signal *COMOS* is output to the first error detecting unit 425. When the switch control signal *SWCONS* is subsequently provided to the switching unit 415, the complex output signal

COMOS is output to the second error detecting unit 440. Accordingly, an initial input of the complex output signal *COMOS* may be provided to the first error detecting unit 425 and generate the error signal *OFFSETS* as described above.

When the generated error signal *OFFSETS* is applied to the oscillator 455, the oscillator 455 outputs the frequency signal *FRQS*. The frequency signal *FRQS* is combined by, for example, multiplying it with the complex output signal *COMIS* to generate the complex output signal *COMOS*. The output signal *COMOS* is provided to the second error detecting unit 440. The second error detecting unit 440 may thereafter operate, for example, according to a conventional carrier recovery device and perform phase synchronization for recovery of a carrier wave.

Accordingly, frequency and phase errors are detected using the first error detecting unit 425 when the complex output signal *COMOS* is provided, for example, as an initial input, and detected using the second error detecting unit 440 when the complex output signal *COMOS* is subsequently provided, for example, after the initial input. Consequently, a carrier recovery device according to the present invention may detect error and recover a carrier wave more quickly than a conventional carrier recovery device having only, for example, the structure shown for the second error detecting unit 440.

FIG. 6 is a flowchart of operations for recovering a carrier according to a first embodiment of the present invention. FIG. 7 is a flowchart of operations for detecting errors, for example, as described in the flowchart of FIG. 6. FIG. 8 is a flowchart illustrating operations for generating an error signal, for example, as described in FIG. 7. Carrier recovering operations by which error in a complex input signal of an HD TV signal is detected and compensated, will now be described with reference to FIGs. 4 through 8.

In block 610 of FIG. 6, a selection is made between performing a first error detecting function when a pilot signal is not detected in a complex input signal, and performing a second error detecting function when the pilot signal is detected. In block 610, the complex output signal and the complex input signal may refer to the same signal, and the complex input signal may be a vestigial sideband (VSB) signal that is represented as a complex number.

According to the first error detecting function, in block 620, the

location of an error reference signal in the complex output signal is determined from a real number portion of the complex output signal. A variation in a phase angle of the complex output signal is measured and the result of the measurement is provided as an error signal. The complex output signal may be the same as the complex input signal.

Block 620 can include blocks 710 and 720 of FIG. 7. In block 710, the location of a beginning and an end of the error reference signal is determined from the real number portion of the complex output signal. The error reference signal may correspond to a PN63 signal in a field synchronization signal of the complex output signal. Block 710 may be performed by the field synchronization detector 430, and the operation thereof may be as was described therewith.

After block 710, a variation in the phase angle of the complex output signal is measured using a variation in the position of the error reference signal, which may be generated per frame of the complex output signal, according to the result of block 710, and the error signal is generated from the measured variation, in block 720. The variation in the phase angle of the complex output signal *COMOS* corresponds to a variation in a frequency offset of the complex output signal *COMOS*. That is, the variation in the phase angle of *COMOS* is a frequency error of the complex output signal *COMOS*.

Block 720 will now be described with reference to FIG. 8. Referring to FIG. 8, the period of the complex output signal is delayed by an amount L, in block 810. Next, a conjugate complex output signal is generated as a representation of the conjugate of the complex output signal, in block 820. In block 830, the result of block 810 is combined by, for example, multiplying it with the result obtained from block 820. In block 840, an imaginary portion is extracted from the result of block 830. In block 850, a real part is extracted from the result of block 830 and the reciprocal of the extracted real part is generated. In block 860, the imaginary portion of block 840 is combined, for example, by multiplying it with the reciprocal of block 850. An arctangent of the result of block 850 is generated in block 870. In block 880, the arctangent is combined, for example, by multiplying it with a predetermined coefficient signal to generate the error signal. The coefficient signal is

calculated by, for example, the equation $1/(2*\pi*L)$, where L is the length of the sampled error reference signal.

Blocks 810 through 860 may be repeatedly performed a number of times equal to the length of the error reference signal sample, i.e., *L* times. Blocks 810 through 860 may be related to the operations provided in Equation 1. The operations obtained by repeating blocks 810 through 850 *L* times, may correspond to a correlation operation. A variation in the phase angle of the complex output signal can correspond to the frequency error of the complex output signal.

Block 720 may be performed by the frequency error measuring unit 435 of FIG. 4, and, therefore, may perform the operations described for the frequency error measuring unit 435. In block 630 of FIG. 6, a frequency signal with a frequency that varies based on the error signal is generated. Block 630 may correspond to the operation of the oscillator 455 of FIG. 4. Error in the complex input signal may be compensated by combining by, for example, multiplying the complex input signal by the frequency signal. In block 670 of FIG. 6, the frequency signal is multiplied by the complex output signal to generate a complex output signal having compensated error. The complex output signal with compensated error is provided outside of the carrier recovery device according to various embodiments of the present invention.

However, when a pilot signal is detected from the complex input signal in block 610 of FIG. 6, the second error detecting function is performed. In the second error detecting function, frequency and phase errors are detected from a pilot signal contained in the complex output signal corresponding to the complex input signal, at block 640. In block 650, the frequency and phase errors are filtered. In block 660, the frequency signal is generated in response to the result of filtering. Block 670 may be performed as described above. The second error detecting function may be performed by the second error detecting unit 440 of FIG. 4, and may therefore operate in the manner described for the second error detecting unit 440.

FIG. 9 is a block diagram of a carrier recovery device according to a second embodiment of the present invention. FIG. 10 is a flowchart illustrating operations for recovering a carrier according to a second

embodiment of the present invention. FIG. 11 is a flowchart illustrating operations for generating an error signal, for example, as part of the operations illustrated in FIG. 10. An apparatus 900 and operations 1000 relating thereto that recover a carrier wave in a HD TV signal will be described with reference to FIGs. 9 through 11.

Referring to the operations 1000 shown in FIG. 10, in block 1010, a complex output signal, which may be the same as a complex input signal, and a real-number signal, that represents a real number part of the complex output signal, are received. The location of an error reference signal in the complex output signal is determined from the real-number signal, and a variation in a phase angle of the complex output signal is measured to generate the variation as the error signal. Block 1010 may be performed by an error detecting unit 915 in the apparatus 900 of FIG. 9.

Referring to FIG. 9, the apparatus 900 includes an error compensating unit 910, the error detecting unit 915, and an oscillator 930. A carrier signal, which is converted into a digital signal, is provided as an input signal *INS* to a complex filter 905. The complex filter 905 filters the input signal *INS* and provides it as a complex input signal *COMIS* that is a complex number signal. The complex input signal *COMIS*, that may be initially input to the error compensating unit 910, is provided to the error detecting unit 915 as the complex output signal *COMOS* whose error may not yet to be compensated. A real-number signal *REALS*, which represents a real part of the complex output signal *COMOS*, is also applied to the error detecting unit 915.

Block 1010 of FIG. 10 may include blocks 1110 and 1120 as shown in FIG. 11. In block 1110, the location of the beginning and end of the error reference signal are detected based on the real-number signal. In block 1120, the complex output signal is received, a variation in a phase angle of the complex output signal is measured using a variation in the position of the error reference signal generated per frame of the complex output signal, according to the detected positions, and the variation in the phase angle is output as the error signal. Blocks 1110 and 1120 may be performed by a field synchronization detector 920 and a frequency error measuring unit 925. The error detecting unit 915 may be configured as shown for the first error

detecting unit 425 according to the first embodiment of the present invention. The error measuring unit 925 may include the elements of the frequency error measuring unit 435 shown in FIG. 5.

In block 1020 of FIG. 10, a frequency signal *FRQS* with a frequency that varies in response to the error signal *OFFSETS* output from the error detecting unit 915 is generated by the oscillator 930. The frequency signal *FRQS* is combined by, for example, multiplying it with the complex input signal *COMIS* to compensate for an error in the complex input signal *COMIS*.

In block 1030 of FIG. 10, the frequency signal *FRQS* is applied to the error compensating unit 910 and multiplied by the complex input signal *COMIS* to generate the complex output signal *COMOS* whose error is compensated. The complex output signal *COMOS* may be provided outside of the carrier recovery device 900.

A circuit that measures error in a data signal according to a third embodiment of the present invention will now be described. The circuit may be as shown for the first error detecting unit 425, and consequently, will be referred to as "circuit 425" and reference will be made to FIG. 4. The circuit 425 includes a field synchronization detector 430 and a frequency error measuring unit 435. The circuit 425 detects an error contained in an input data signal *COMOS*. The data signal may be a VSB signal that is converted into a complex number. A field synchronization signal including three PN 63 signals is generated for each field of the VSB signal. The circuit 425 measures an error in the input data signal *COMOS* using the three PN63 signals and generates the error as an error signal *OFFSETS*.

The field synchronization detector 430 determines the location of the beginning and the end of an error reference signal in the data signal *COMOS* from a real-number signal *REALS*, which represents a real part of the data signal *COMOS*. The error reference signal may be a PN63 signal in the field synchronization signal of the data signal *COMOS*.

The frequency error measuring unit 435 measures a variation of a phase angle of the data signal *COMOS* using a variation in the position of the error reference signal, which is generated per field of the data signal *COMOS*, in response to a signal *FSO* from the field synchronization detector 430, and provides the measured variation of the phase angle as the error signal

OFFSETS. The frequency error measuring unit 435 may include the same elements shown in FIG. 5. Using the circuit 425, it may be possible to detect an error in the VSB signal from the PN63 signal in the VSB signal, even if a pilot signal is not detected from the VSB signal.

Accordingly, embodiments of the present invention provide apparatus and methods that may quickly recover a carrier even when a pilot signal may be difficult to detect. For example, in some embodiments, a PN63 signal that is contained in a field synchronization signal of a VSB signal is used to recover the carrier.

While this invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.